91602
new 82-10

ontario hydro
research division

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research if
Reproduced in Whole or in Part

To: Mr. R.C. Seaton
Project Manager
System Control Center Relocation Project
Design and Development-Transmission Division

RELIABILITY ASSESSMENT OF THE HVAC SYSTEM FOR THE CLARKSON SYSTEM CONTROL CENTER

L. Wang
Senior Engineer-Reliability
Reliability and Statistics Section
Operations Research Department

A reliability assessment was carried out for the heating, ventilating and air-conditioning system to be installed at the new System Control Center at Clarkson. The predicted unavailabilities and mean times between failures for the critical load areas are within the specified reliability targets. The computed mean downtimes for the computer room and the electrical equipment room are longer than the target value of 0.5 hour, which may not be attainable for a practical HVAC system.

1. INTRODUCTION

The new System Control Center (SCC) will be housed in a three-story building under construction at Clarkson. The continuous operation of the equipment in the new SCC requires a dependable air-conditioning system to provide a favorable operating environment. The heating, ventilating and air-conditioning (HVAC) system for the new SCC is designed with a high degree of redundancy to fulfill this requirement.

At the request of the System Control Center Relocation Project Department, a reliability assessment of the HVAC system for the new SCC was carried out. This report summarizes the results of this assessment.

2. SUMMARY OF RESULTS

The predicted unavailabilities, the mean times between failures (MTBF) and the mean down times of the air conditioning systems for the four load areas of the new SCC are given in Table 1, with the reliability targets given in brackets following the computed indices. Details of the computations are given in the Appendix.

job	file	date	report no.
72-212-422	813.07	September 27, 1988	88-219-K

89-04559/

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf:

(a) makes any warranty, express or implied with respect to the use of any information, apparatus, method or process disclosed in this report or that such use may not infringe privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

The results in Table 1 show that the unavailability and the MTBF indices for the essential load areas (the control room, the computer room, and the electrical equipment room) are well within the specified reliability requirements. The mean down times of air-conditioning systems for the computer room and the electrical equipment room are longer than the specified values. An air-conditioning system failure in an essential load area can occur only when several components in the HVAC system fail simultaneously, exhausting all redundancies in the system. In such a case air-conditioning service can be restored only by completing the repair work of at least one of the failed components. It is unlikely that the mean repair times of the HVAC system components can be reduced significantly. Hence the specified mean down time of 0.5 hour for the computer room and the electrical equipment room air-conditioning systems may prove to be difficult to meet.

TABLE 1

HVAC System Reliability Indices

Load area	Unavailability	MTBF, yr.	Mean down time, hr.
Control room	5.09E-6 (9.0E-5)	64 (5)	2.86 (4)
Computer room	5.09E-6 (5.7E-6)	64 (10)	2.86 (0.5)
Electrical equip rm	5.09E-6 (5.7E-6)	64 (10)	2.86 (0.5)
Admin area	0.83E-3 (-)	1.2 (-)	4.77 (-)

An interruption of power supply to the HVAC system would cause it to stop functioning. The probability of occurrence of this event is approximately 2.0E-9, with a mean downtime of 4.0 hours.

As mentioned before, the HVAC system for the new SCC is designed with a high degree of redundancy. An air-conditioning system composed of components identical to those in the HVAC system for the new SCC but with no redundancy has an unavailability of 2.91E-3 (equivalent to a failure frequency of 4.72 times per year and a mean down time of 5.41 hours). This simple example shows that the high reliability levels of the HVAC system for the new SCC are achieved through redundancy. Real-life experience tells us that most air-conditioning systems with no redundancies perform much more reliably than the one given in the above example. This suggests that the results obtained in this assessment are not overly optimistic.

Approved:

A. H. Chung
Manager
Operations Research Department

Submitted:

L. Wang
Senior Engineer-Reliability
Reliability and Statistics Section

LW:cmh

APPENDIX

1. SYSTEM DESCRIPTION

The HVAC system is designed to perform three major functions: heating, cooling and air handling. A simplified diagram of the HVAC system is given in Figure A.1. Cooling is provided by three open-drive centrifugal chiller units, any two of which will be capable of handling the full building load. Any one unit can be operated to provide adequate capacity for essential loads, including the control room, the computer room, and the electrical equipment room, and their supporting areas. Chilled water is circulated to the air handling units for air-conditioning in required areas.

Much of the heating energy requirement can be produced from recovering the heat rejected by the operating chillers. This heat is available at a low temperature. Four pipe fan coil systems will be provided for perimeter space heating. Other fan coil heaters will also be provided in upper floor ceiling plenums and other areas requiring heating. A supplemental electric boiler will be installed to maintain heat recovery circuit temperatures during low internal load periods and to provide higher temperature water for entrance and bridge heating.

Duplicate central station air handling units will be provided for the three critical areas, including the control room, the computer room and the electrical equipment room. They will be installed in separate HVAC equipment rooms to provide standby capacity for each of the critical load areas in the event of equipment failure, maintenance, or even the destruction of one HVAC equipment room. The administration area will be serviced by a separate central station air handling unit located in the main HVAC equipment room.

A fixed amount of outside air will be supplied to all air handling unit, except the one for the administration area, at all seasons to ensure a constant quantity and quality of ventilation and to avoid potential freeze up problems associated with winter operation.

Since the air handling unit for the administration area may have different operating requirement, and is not considered an essential load, nor is it a large heat energy source, outside air economizer cooling will be provided to reduce winter refrigeration requirements. Operation of the chiller will not be required to provide cooling to the interior office spaces when outdoor ambient conditions allow direct use of outdoor air.

The air handling unit for the administration area is designated to serve as a backup for the units for both the computer room and the electrical equipment room. Backup for the control room air handling unit comes from those for the computer room.

An electronic control and monitoring system featuring distributed control, central monitoring and central control override will be provided to manage operating conditions. Automatic changeover from operating to standby equipment will be initiated in the event of a failure. Abnormal operating conditions will be alarmed to the central station. Provision will be made to communicate with an off-site monitoring facility through a telephone line.

2. FAILURES IN THE HVAC SYSTEM

In view of the designed redundancies in the HVAC system, failures of a single component may cause a temporary interruption of air-conditioning service to a particular load area. The duration of the temporary interruption is equal to the time required to complete an automatic or manual change-over operation. The durations of such temporary interruptions of air conditioning service are assumed to be sufficiently short so that they do not cause any problem in the operation of the SCC. Therefore, such temporary interruptions of air-conditioning service are not considered as system failures.

If no change-over operation can restore air-conditioning service, the system is considered failed.

The justifications for the definition of system failure stated above are based on the following considerations:

(1) the operation of the HVAC system is constantly monitored by an electronic monitoring system at two different locations in the SCC, and

(2) the operation of the electronic monitoring system can be tested at regular intervals to ensure that it functions normally.

Note that the above definition of system failure does not include any specification on the down time of the air-conditioning system. In reality, only air-conditioning system outages which last longer than a given length would affect the operation of the equipment in the SCC. Outages with downtimes shorter than this value are tolerable and technically they should not be classified as system failures. However, it is believed that only a small portion of air-conditioning system failures falls in this category, and the specification of a minimum downtime in the system failure definition would unnecessarily complicate the assessment process. Excluding the minimum downtime specification in the system failure definition results in lower reliability (or higher risk) indices for the air-conditioning systems.

3. METHOD OF ASSESSMENT

3.1 Assumptions

The following assumptions were made in this study:

- The electronic control and monitoring system is tested at regular intervals to ensure its proper functioning. This process reduces the probability of malfunctions in the HVAC system without being detected by the monitoring system or hidden failures of the monitoring system itself to a negligible level.

- At the detection of an abnormality in the HVAC system, manual change-over operations can be completed in a short time without causing difficulties in the operation of the SCC.

- The air-conditioning systems for the control room, the computer room, and the electrical equipment room operate in the cooling mode at all seasons. These systems are not affected by component failures in the heating subsystem.

- The air-conditioning system for the administration area operates in the cooling mode for two thirds of the year, and in the heating mode for the remainder of the time.

- The air handling unit for the administration area can backup the air handling units for the computer room, or those for the electrical equipment room, but not for both rooms at the same time.

- It may be possible to have free cooling utilizing outside air during the cool months. This mode of cooling operation can be applied to the administration area, the computer room, or the electrical equipment room. However, the effectiveness of this mode of operation is not certain, and therefore is not included in the reliability assessment.

- Component failures occur independently. Common-cause failures, such as those due to fire and earth-quake, are not included in the assessment.

- The effect of annual maintenance of the water chillers, fluid coolers, and air handling units are incorporated in the assessment. The duration of annual maintenance of the water chiller and fluid cooler combination is assumed to be one week, and that of the air handling unit is one day.

- Under normal conditions two chillers will be operated while the third will be placed on standby. The operating and the standby units will be rotated on a regular basis. The standby unit will undergo weekly start-up tests. The probability of occurrence of a start-up failure is assumed to be 0.05.

3.2 Logic Diagrams

In view of the designed redundancies in the HVAC system and the assumed independence of system components, the logic diagram approach seems to be the most suitable method for this study. A system represented by a logic diagram is considered working if there is a path between the input and output nodes of the diagram.

The HVAC system can be separated into three subsystems each of which performs one of the following three functions: cooling, air handling and heating. The logic diagrams for these subsystems are given in Figures A.2 to A.4. Note that the air handling subsystems for the different load areas in the SCC are not all identical. Backup air handling provisions for the essential load areas are indicated in the logic diagram in Figure A.3.

3.3 Assessment Procedure

The reliability of the air-conditioning system for each load area of the SCC is assessed separately. The seasonal operating modes of the air- conditioning systems are incorporated in the assessment.

The control room air-conditioning system is expected to operate in the cooling modes all year round. Its reliability indices can be calculated from the logic diagram of the chilled water subsystem in series with that for the appropriate air handling subsystem, with due consideration given to the availability of the backup arrangement.

The computer room and the electrical equipment room air-conditioning systems are also expected to operate in the cooling mode all the time. Their reliability indices can be calculated in a manner similar to that for the control room.

The administration area air-conditioning system is assumed to operate in the cooling mode for eight months in late spring,summer and fall, and in the heating mode for the remainder of the year. Reliability of the system in the cooling mode can be calculated from the logic diagrams of the chilled water subsystem and the appropriate air handling subsystem in series. In the heating mode, it can be calculated from the logic diagrams of the water heating and air handling subsystems in series. There is no backup arrangement for this system.

4. COMPONENT FAILURE DATA

No published failure data for air-conditioning system components were found in the literature. Failure data of similar components were used as references in selecting the failure rates and the mean repair times for these components. Both the reference data and the failure data used in this study are listed in Table A.1. In cases where no reference data could be found, suitable values were assumed based on judgement. The assumed failure data are believed to be conservative.

TABLE A.1

Component Failure Data

Component	Reported Data: Failure rate, /yr.	Reported Data: Mean Repair time, hrs.	Source*	Data used in study: Failure rate, /yr.	Data used in study: Mean repair time, hrs.
Chilled water pump	0.435	5.5	(1)	0.435	5.5
Flotrex disch. & bal. valve	0.083	3.7	(2)	0.083	3.7
Suction guide & strainer	0.019	10.0	(2)	0.019	10.0
Butterfly valve, manual	0.013	5.5	(2)	0.13	5.5
Condenser pump	0.435	5.5	(1)	0.435	5.5
Chiller/heat exchanger	0.041	24.0	(1)	0.2	24.0
Pneumatic valve	0.02	4.0	(2)	0.2	4.0
Pipe, 4-6", per meter	3.2E-6	-	(2)	3.2E-6	6.0
Temperature control valve	-	-	-	0.1	5.0
Diff. pressure bypass valve	0.074	7.6	(2)	0.074	7.6
Fluid cooler	-	-	-	0.1	5.0
Air handling unit	-	-	-	0.5	5.0
Dampers & controls	-	-	-	0.01	5.0
Ductwork	-	-	-	0.000876	5.0
Heating coil	0.0135	8.0	(2)	0.0135	8.0
Heat recovery pump	0.435	5.5	(1)	0.435	5.5
Electrical boiler	0.047	21.8	(1)	0.2	24.0
Hot water pump	0.435	5.5	(1)	0.435	5.5

* Source of data:

(1) Ontario Hydro Design and Development Division Report No. 76095, June, 1976.
(2) Ontario Hydro Design and Construction Branch Report No. 86296, Nov. 1986.

5. IMPACT OF REPAIR DELAYS

After the failure of a component in the air conditioning system, repair efforts could be delayed if the needed spare parts are not readily available. Such delays would adversely affect the reliability levels of the air-conditioning systems for the critical load areas in the new SCC. The impact on system reliability due to the lack of spare parts for one component may not be the same as that for another. It is useful to assess such impacts so as to determine the levels of spares needed for various key components in the HVAC system. Assessments were carried out by assuming 4-week delays in repairs following failures of some key components. The results of these assessments are given in Table A.2. Note that in these assessments the effect of repair delays in more than one type of component is not considered.

TABLE A.2

Impact of Repair Delays on HVAC Reliability for Critical loads

	Unavailability		MTBF, yrs.	
Component	Without delay	With delay	Without delay	With delay
Chilled water pump	5.09E-6	6.65E-6	64.2	62.1
Condenser pump	5.09E-6	6.65E-6	64.2	62.1
Chiller	5.09E-6	8.79E-6	64.2	63.0
Air handling unit	5.09E-6	51.6E-6	64.2	54.7

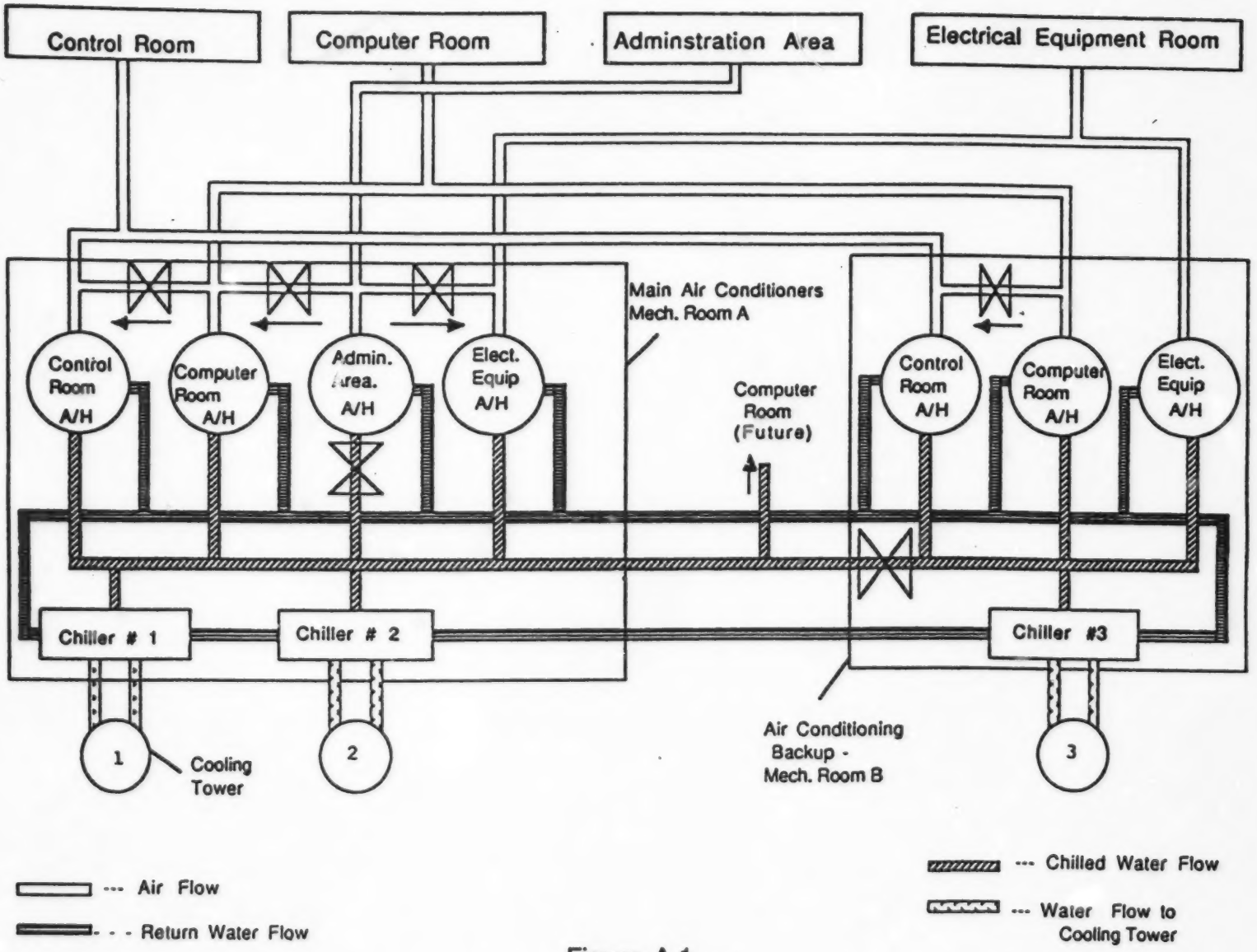

Figure A.1
Clarkson SCC HVAC System

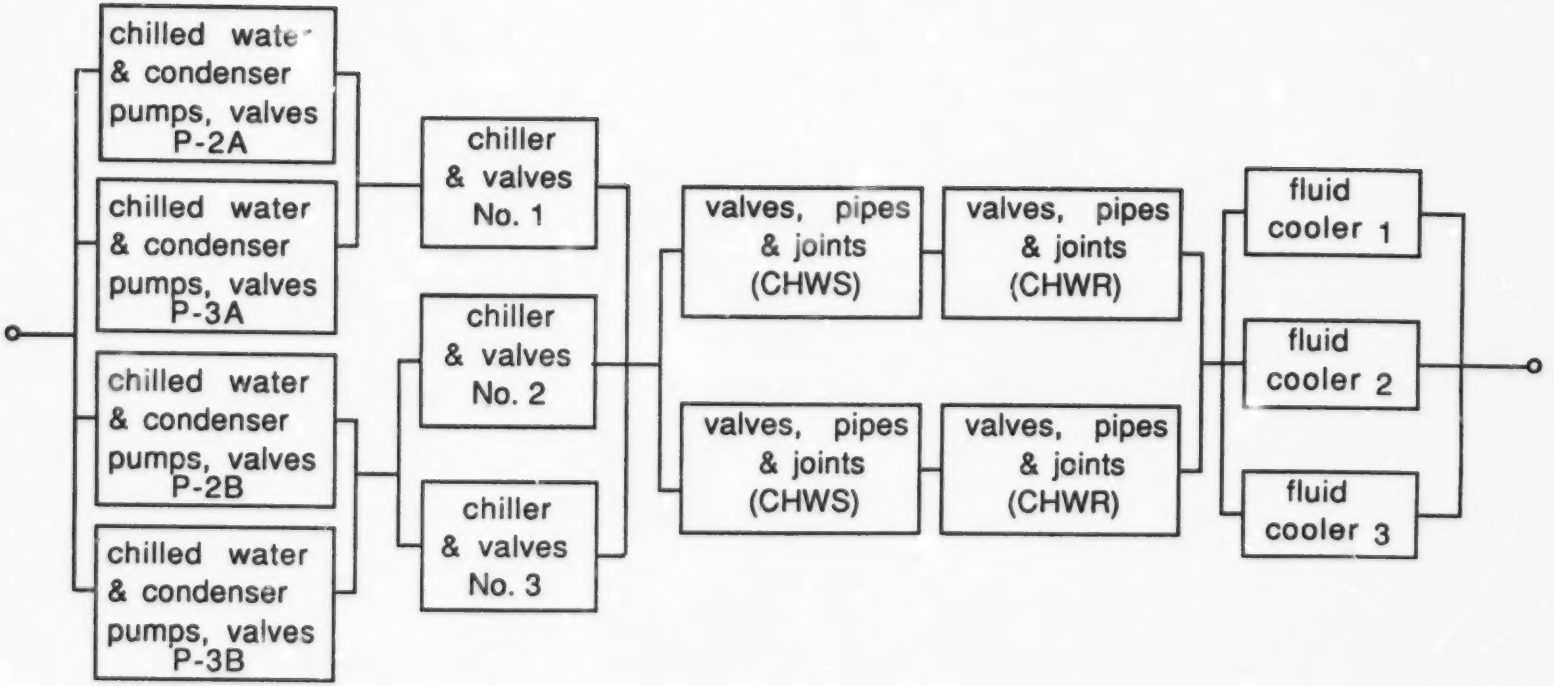
chilled water & condenser pumps, valves P-2A
chilled water & condenser pumps, valves P-3A
chilled water & condenser pumps, valves P-2B
chilled water & condenser pumps, valves P-3B
chiller & valves No. 1
chiller & valves No. 2
chiller & valves No. 3
valves, pipes & joints (CHWS)
valves, pipes & joints (CHWS)
valves, pipes & joints (CHWR)
valves, pipes & joints (CHWR)
fluid cooler 1
fluid cooler 2
fluid cooler 3

Figure A.2
Chilled Water Subsystem

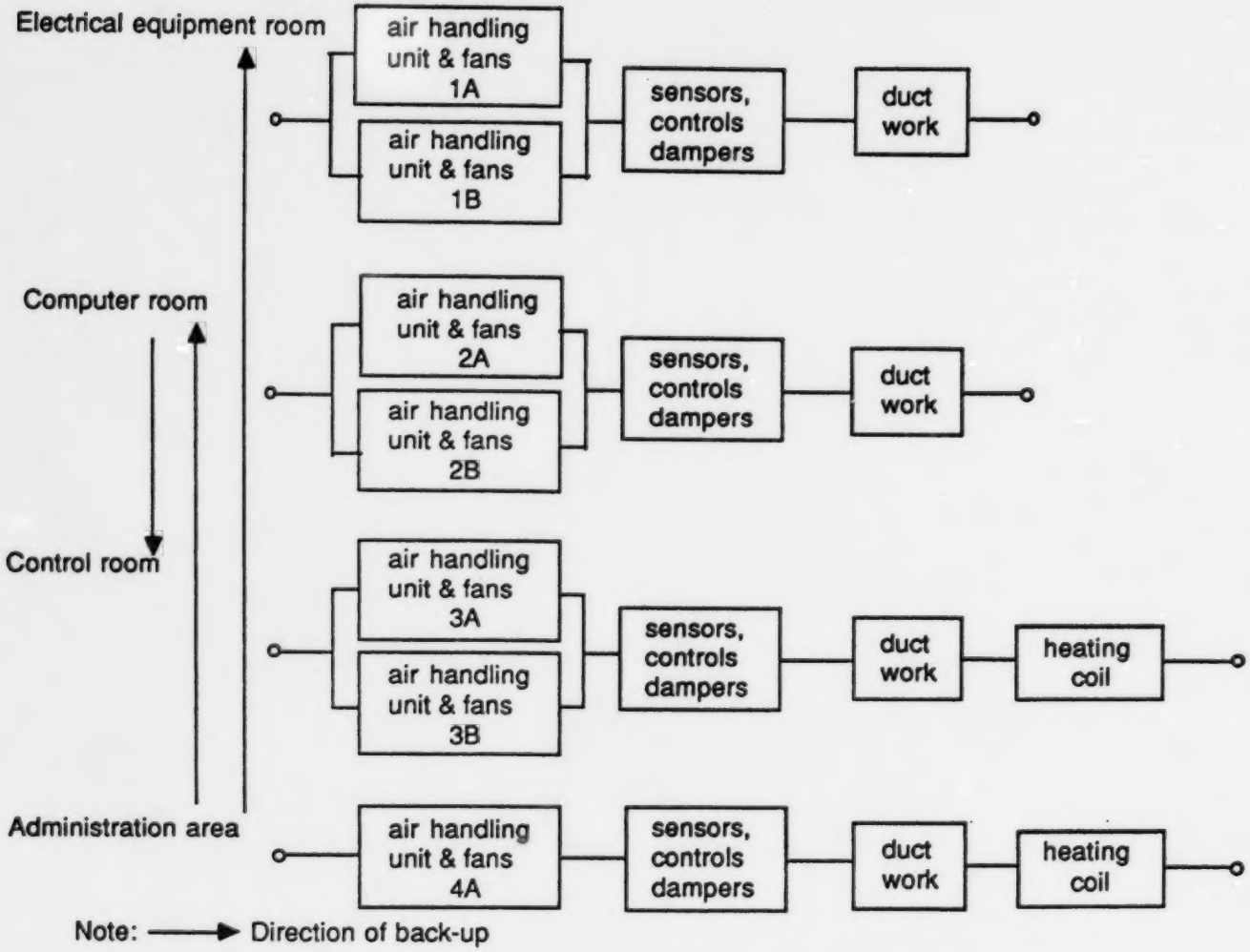

Figure A.3
Air Handling Subsystem

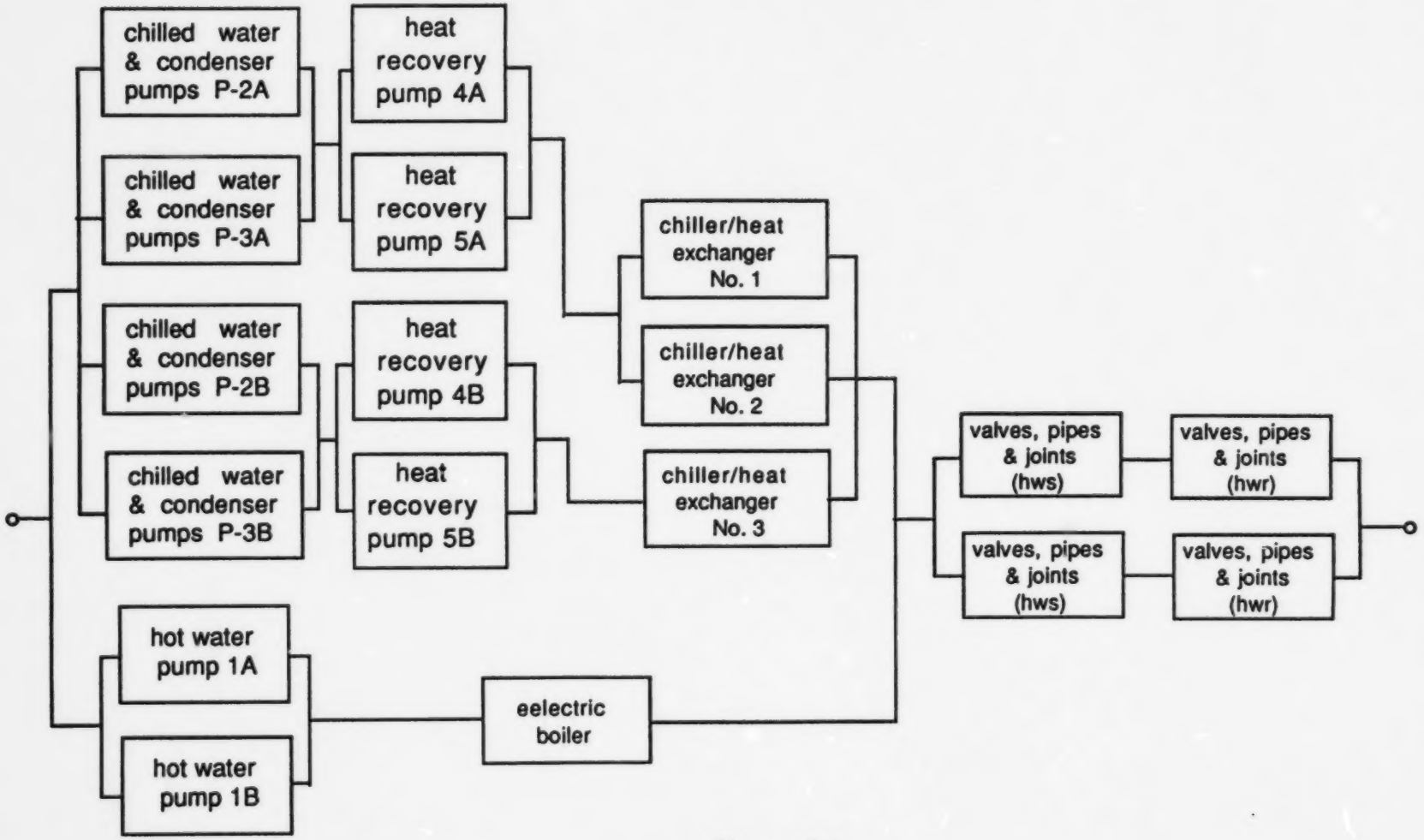
chilled water & condenser pumps P-2A
chilled water & condenser pumps P-3A
chilled water & condenser pumps P-2B
chilled water & condenser pumps P-3B
heat recovery pump 4A
heat recovery pump 5A
heat recovery pump 4B
heat recovery pump 5B
chiller/heat exchanger No. 1
chiller/heat exchanger No. 2
chiller/heat exchanger No. 3
valves, pipes & joints (hws)
valves, pipes & joints (hwr)
valves, pipes & joints (hws)
valves, pipes & joints (hwr)
hot water pump 1A
hot water pump 1B
eelectric boiler

Figure A.4
Water Heating Subsystem